SCIENCE LETTERS

ISSN: 1675-7785
eISSN: 2682-8626

Available online at https://scilett-fsg.uitm.edu.my/

Science Letters 20(2) 2026, 107-119.

Science Letters

Melastoma malabathricum L. *leaves* (senduduk) extract in a water-based emulsion: physical and chemical stability study and bacterial inhibition activity

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ARTICLE INFO

Article history:
Received 22 November 2025
Revised 21 January 2026
Accepted 25 January 2026
Published 30 June 2026

Keywords:
Melastoma malabathricum L.
water-based emulsion
antibacterial activity
bioactive compounds

DOI:
10.24191/scl.v20i2.10375

ABSTRACT

Melastoma malabathricum L. (MB) is a medicinal plant with therapeutic properties for treating scars resulting from smallpox, pimples, and skin blemishes. The active compound found in MB leaves can create a high-quality and efficient product that can effectively prevent the growth of bacteria. This study investigates the antimicrobial potential and stability of MB leaves extract in a water-based emulsion, emphasizing its application in cosmetic and pharmaceutical formulations. Leveraging traditional uses and scientific findings, the plant's bioactive compounds, including saponins, flavonoids, tannins, and phenolic acids, are recognized for their antibacterial properties. The research employed solvent extraction techniques, notably the maceration method, to isolate these bioactives, which were incorporated into emulsions at varying concentrations. This study evaluates the antibacterial activity and stability of MB leaves extract in a water-based emulsion. Extracts were prepared using methanol and ethanol at different concentrations and durations. Phytochemical screening confirmed the presence of tannins, saponins, and flavonoids, with 50% methanol yielding the highest bioactive content. The 96-hour methanol extract showed the strongest antibacterial activity against *Staphylococcus aureus* (14 mm) and *Escherichia coli* (19 mm). Water-based emulsions with 1% plant extract retained moderate antibacterial effects and maintained stable pH (4.5–5.5) over 21 days at 4°C. These findings support the extract's potential as a natural antibacterial agent in topical or cosmetic formulations.

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https://doi.org/10.24191/scl.v20i2.10375

INTRODUCTION

Melastoma malabathricum L. (MB), commonly called Senduduk, is a widely recognized medicinal plant valued for its diverse bioactive compounds, including flavonoids, tannins, and phenolic acids (Amalia et al., 2019; Fiardilla et al., 2020). These compounds exhibit significant antibacterial, antioxidant, and anti-inflammatory properties, making the plant a promising candidate for cosmetics, pharmaceuticals, and natural preservative applications (Joffry et al., 2012). Traditionally, MB has been employed in herbal medicine to treat wounds, diarrhea, and inflammation, reflecting its extensive ethnopharmacological relevance. Recent advancements in phytochemistry and pharmacology have shed light on its potential as a natural antimicrobial agent, particularly in formulations vulnerable to microbial contamination.

Water-based emulsions, which consist of water as the continuous phase and oil as the dispersed phase, serve as efficient delivery systems for hydrophilic and lipophilic compounds (S. Sasidharan et al., 2010). These emulsions are extensively utilized in the cosmetic and pharmaceutical industries due to their eco-friendly and versatile nature. However, one of their primary challenges is ensuring physical and chemical stability while preventing microbial growth, which can compromise product safety and efficacy. Conventional synthetic preservatives, though effective, face growing consumer concerns regarding potential health and environmental risks. Consequently, there is a rising interest in exploring plant-based natural preservatives like MB extract.

Prior research into MB has primarily examined its phytochemical profile and its effectiveness in inhibiting common pathogens like *Escherichia coli* and *Staphylococcus aureus* (Che Omar et al., 2013; Sri Hainil et al., 2021, Rizky et al., 2025). These investigations have highlighted the plant's potential to inhibit bacterial growth effectively. However, limited research has been conducted on its application in emulsified systems. Specifically, the integration of MB extract into water-based emulsions and its subsequent impact on emulsion stability, bioactivity, and storage performance remain underexplored.

This study aims to bridge this knowledge gap by systematically investigating the physical and chemical stability of water-based emulsions enriched with MB extract. Furthermore, the antibacterial activity of these formulations will be assessed to evaluate their practical applications. Key objectives include understanding the interactions between plant extract components and emulsion matrices, evaluating stability under various storage conditions, and determining their efficacy in inhibiting bacterial growth. The findings of this research will contribute to the development of sustainable, effective, and natural alternatives to synthetic preservatives, aligning with the growing demand for eco-friendly and health-conscious products.

METHODOLOGY

Fig. 1 shows the research methodology consists of preparing the materials for the experiments, pretreatment *Melastoma malabathricum* L. leaves, extraction, phytochemical screening of the extracted plant, FTIR analysis, preparing the formulation of water-based emulsion with plant extract, run the stability test of pH and antibacterial test.

Material

The leaves of MB and water-based emulsion were purchased from a local vendor for use in this research project. The other materials utilized in this research were methanol, ethanol, distilled water, Mannitol Salt Agar, Nutrient Agar, *Staphylococcus aureus* and *Escherichia coli.*

Pretreatment plant sample

The leaves of MB are subjected to triple drying in a hot oven at 100°C for one hour each time to ensure complete drying. The dried leaves are ground, and the resulting powder is filtered through a 400-micron sieve. The powder is stored in sealed plastic bags and shielded from light until it is utilized.

https://doi.org/10.24191/scl.v20i2.10375

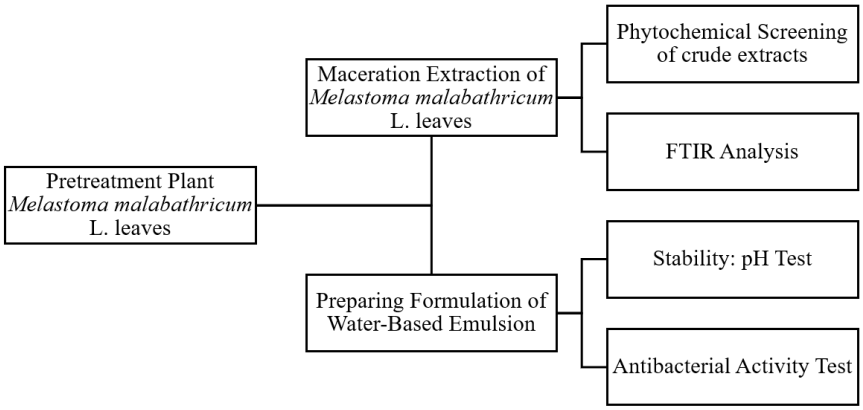

Fig. 1. Overall Flow of Research Methodology.

Maceration extraction of plant

20 g of MB leaves in powdered form are immersed in 400 ml of two different solvents, methanol and ethanol, at a ratio of 1:20 (w/v). The extraction process is carried out for two different time durations: 72 hours and 96 hours. Additionally, two solvent concentrations are used: 50% and 100% concentration for both solvents. The mixture is left to soak at 25°C (room temperature), and this method of extraction is known as the maceration technique. The solvent was evaporated using a rotary evaporator set at a temperature of 50°C with a rotational speed ranging from 90 to 150 rpm to efficiently and gently remove solvents from samples by evaporation (Mohd, 2019). The crude solution was measured and placed in an appropriate receptacle in a refrigerator to inhibit the breakdown of the substances by living organisms and shield them from exposure to light. Determine the percentage yield of the crude sample using Equation (1):

$$\% \, Yield = \frac{\text{Weight of the crude extract (g)}}{\text{Weight of the ground sample (g)}} \times 100\% \quad (1)$$

Phytochemical screening of crude extracts

Phytochemical screening was carried out to identify the major classes of bioactive compounds present in the crude extracts. This qualitative analysis provides an initial understanding of the chemical constituents that may contribute to the plant's therapeutic properties and guides further detailed investigations. Flavonoids, saponins, and tannins were selected because they are the major phytochemicals reported in MB leaves and are strongly associated with antibacterial activity and compatibility with water-based emulsions. Other phytochemicals such as terpenoids and alkaloids were not prioritised due to their lower relevance to aqueous systems and the specific objectives of this study. Flavonoids were screened by treating the crude extracts with 2 ml of 2% sodium hydroxide solution. According to Hasan et al. (2024), the formation of a yellow tint, which fades upon the addition of dilute hydrochloric acid, confirms their presence. Simultaneously, the saponin test was performed by mixing 3 ml of distilled water with the crude extract. The mixture is then shaken vigorously in the test tube for 5 minutes. The formation of a foam layer indicates the presence of saponins (Ringga Novelni et al., 2023). As for the tannin test, the crude extracts were mixed with a few drops of ferric chloride solution in a test tube. The blue-black or dark green colour that formed indicated the presence of tannins (Ringga Novelni et al., 2023).

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FTIR analysis

The active compounds' functional groups were identified using Fourier Transform Infrared Spectroscopy (FTIR) analysis on a Perkin Elmer Spectrum One spectrophotometer. Infrared spectra were collected at a resolution of 4 cm^{-1} over the range of 400-4000 cm^{-1} with 3486 scans (Hasan et al., 2024). The sample port was cleaned by using acetone to remove any variation caused by contamination during scanning. The spectra yielded from the sample scanning were collected and studied. The resulting data was used for subsequent analysis.

Preparing the formulation of a water-based emulsion

The water-based emulsion (WBE) was formulated by incorporating each plant extract obtained from maceration extraction. Each formulation had a total weight of 0.10 g, containing 1% (w/w) plant extract. The remaining components consisted of the emulsion base without any antibacterial agents. A blank WBE without plant extract was prepared and used as the negative control for subsequent antibacterial evaluation.

Stability pH Test

A 10 g water-based emulsion containing 1% MB extract was stored for 21 days at two different temperatures, 4°C and 25°C (room temperature). The pH of the sample was measured using a pH meter (Rahman & Zamanhuri, 2023).

Antibacterial activity test

The antibacterial assay was conducted using the disc diffusion method. The tested bacteria, *Staphylococcus aureus* and *Escherichia coli*, were sub-cultured onto mannitol salt agar and nutrient agar plates using a sterile wire loop. The bacteria were spread evenly on the agar plate with the help of a sterile cotton swab. The plates were then incubated at 37°C for 24 hours to allow bacterial growth. After incubation, the crude extracts were pipetted onto filter paper discs, not direct agar application on the upper layer of the agar plate, and the plates were positioned upside down before being incubated overnight at 37°C. The disc diffusion method was used for testing all bacterial strains (Mohd, 2019). The inhibition zones around the discs were measured in millimeters (mm) to determine the antibacterial activity of the extracts.

RESULTS AND DISCUSSION

Yield percentage of crude extract

The percentage yield of MB leaves crude extracts obtained through maceration using methanol and ethanol solvents is summarized in Table 1. For a 72-hour maceration period, methanol yielded 29.50%, while ethanol produced a lower yield of 19.85%. Extending the extraction period to 96 hours slightly increased the yield for both solvents, with methanol reaching 29.70% and ethanol rising to 22.30%. These results indicate that methanol consistently resulted in higher yields than ethanol, regardless of extraction time. This is primarily due to methanol's greater polarity, which arises from its shorter carbon chain compared to ethanol. The increased polarity enhances its ability to dissolve a wider range of polar phytochemicals, such as flavonoids (Jessica Clifton, 2024). Additionally, prolonged extraction time allows more effective contact between the solvent and plant material, thereby improving the diffusion of bioactive compounds into the solvent. Nonetheless, the ethanol-based yields in this study were slightly lower than those in the reference, which may be attributed to differences in solid-solvent ratios or the specific plant matrix used.

Further analysis of the effect of solvent concentration on extraction efficiency is shown in Table 1. The results demonstrated that a 50% methanol solution yielded the highest extraction value at 52.55%, significantly exceeding the 29.50% yield from 100% methanol. A similar pattern was observed for ethanol, where 50% ethanol produced a yield of 50.85%, while 100% ethanol resulted in only 14.85%. These findings suggest that aqueous-alcohol mixtures are more effective than pure solvents for extracting phytochemicals. The presence of water likely enhances plant tissue permeability and facilitates the swelling

https://doi.org/10.24191/scl.v20i2.10375

of cell walls, which improves the penetration of the solvent and the release of active compounds. This observation is consistent with the study by Amalia et al. (2019), which found that 70% ethanol was more efficient than 96% ethanol in extracting constituents such as flavonoids, saponins, and tannins from MB leaves. Therefore, solvent polarity, influenced by alcohol-water ratios, is a key factor in optimizing phytochemical extraction from plant materials.

Table 1. Yield percentage of different extracts of *Melastoma malabathricum* L

	Sample Extract	Percentage of yield (%)
100% solvent concentration	72h Methanol	29.50
	96h Methanol	29.70
	72h Ethanol	19.85
	96h Ethanol	22.30
72 hrs maceration time	50% Methanol	52.55
	100% Methanol	29.50
	50% Ethanol	50.85
	100% Ethanol	14.85

Phytochemical screening

Phytochemical screening revealed varying presence of flavonoids, saponins, and tannins depending on the solvent composition and maceration time as shown in Fig. 2. As shown in Table 2, flavonoids were only detected in the 50% methanol and 50% ethanol extracts, while absent in the 100% concentrations, regardless of extraction duration. This indicates that a moderate polarity solvent system, formed by combining alcohol with water, enhances the solubility and extraction efficiency of flavonoid compounds. Flavonoids, being polar, are likely stabilized and better solubilized when water is present, aiding penetration and preventing structural degradation (Miao et al., 2022; Sankeshwari et al., 2018). The absence of flavonoids in pure alcohol extracts may be attributed to the denaturation or insufficient solubility of certain glycosylated flavonoids, especially during prolonged maceration. In contrast, the saponin test results, summarized in Table 2, showed a consistent positive outcome across all solvent types and concentrations. This uniform detection implies that saponins in *Melastoma malabathricum* L. leaves are highly extractable regardless of the solvent polarity. Their amphiphilic nature facilitates solubility in both methanol and ethanol, as well as their aqueous mixtures. This robustness not only supports their ease of extraction but also aligns with their reported stability in emulsified systems. The strong presence of saponins may significantly contribute to the plant's antibacterial and anti-inflammatory effects by disrupting microbial membranes and activating host immunity.

Regarding tannins, Table 2 indicates that they were present in all extracts, although the coloration varied with the solvent used. A blue-black coloration appeared in methanol extracts, while ethanol extracts turned dark green. This visual difference corresponds to known reactions between ferric chloride and different tannin types, likely reflecting the presence of both hydrolyzable and condensed tannins in the leaf material (Kamarudin et al., 2021; Bharudin et al., 2013). The persistent detection of tannins further confirms their abundance and extractability from the plant matrix. Given their protein-binding ability and antimicrobial properties, their presence supports the therapeutic potential of *Melastoma malabathricum* L. in topical formulations. Therefore, from Table 2, saponins and tannins appear to be widely distributed and easily extracted, while flavonoids require more specific solvent concentrations, especially 50% methanol or ethanol for their detection.

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Table 2. Result phytochemical screening with different extracts of *Melastoma Malabathricum* L.

	Sample Extract	Bioactive Compound		
		Flavonoid	Saponin	Tannin
100% solvent concentration	72h Methanol	-	+	+
	96h Methanol	-	+	+
	72h Ethanol	-	+	+
	96h Ethanol	-	+	+
72 hrs maceration time	50% Methanol	+	+	+
	100% Methanol	-	+	+
	50% Ethanol	+	+	+
	100% Ethanol	-	+	+

Key: (+): Presence, (-): Absence

(a) (b) (c)

Fig. 2. Presence of (a) Flavonoid, (b) Saponin and (c) Tannin in the 50% Methanol sample\

FTIR Analysis

As shown in Fig. 3(a), the FTIR spectrum of *Melastoma malabathricum* L. extract using 50% methanol presents a broad absorption band around 3339.48 cm^{-1}, indicating the presence of hydroxyl (O–H) groups and a medium intensity at approximately 1638.92 cm^{-1} corresponding to carbonyl Amide I (C=O) stretching. Among all tested samples, this spectrum is one of the richest, clearly revealing functional groups typical of phenolic, flavonoid, and glycosidic compounds. The use of 50% methanol appears optimal, as the solvent's balanced polarity enhances the extraction of both polar and semi-polar phytochemicals. This observation is strongly aligned with the phytochemical screening data in Table 2, which confirmed the abundant presence of flavonoids, tannins, and saponins in this extract. These findings support earlier reports highlighting methanol–water mixtures as effective solvents for recovering bioactive compounds from medicinal plants (Kumar Sharma & Kumar, 2011; Zakaria et al., 2006).

As shown in Fig. 3(b), the FTIR spectrum of the methanol extract after 96 hours reveals strong and distinct absorption peaks corresponding to key functional groups: O–H (~3283.23 cm^{-1}), C–H (~2948.23 cm^{-1}), C=O stretch amide (~1646.95 cm^{-1}), aromatic C=C (~1449.62 cm^{-1}), and C–O (~1109.81 cm^{-1}). These prominent signals suggest the presence of phytochemical constituents such as flavonoids, tannins, and phenolic compounds, which are known for their antibacterial and emulsifying activities. Notably, among all methanol-based extractions, the 96-hour sample demonstrated the most intense and well-defined peaks, indicating more efficient extraction and higher compound recovery over prolonged soaking time.

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This observation aligns with previous reports stating that longer extraction durations can enhance the release of bioactive compounds (Fatema et al., 2024).

The FTIR spectrum of *Melastoma malabathricum* L. leaf extract using 100% ethanol, as illustrated in Fig. 3(c), reveals key functional groups indicative of bioactive compounds. Notable absorption bands appear around 3327.50 cm^{-1}, attributed to O–H stretching vibrations, and at 2973.79 cm^{-1} for C–H stretching, suggesting the presence of alcohols and alkanes. Medium intensity at approximately 1646.59 cm^{-1} represents C=C. Compared to the 50% ethanol extract, the peaks in the 100% ethanol extract are notably less intense and less well-defined. This implies a lower efficiency in extracting polar compounds, which are often more soluble in hydroethanolic mixtures. Nonetheless, the detection of O–H and C=O signals confirm the presence of flavonoids and phenolic constituents, albeit in smaller quantities. The reduced peak intensity also suggests a lower abundance of glycosides and fewer diverse functional groups.

Fig. 3(d) displays the FTIR spectrum of the ethanol-extracted sample after 96 hours, showing a broad O–H stretching band around ~3327.50 cm^{-1}, along with peaks at ~2973.79 cm^{-1} (C–H) and ~1646.59 cm^{-1} (C=O). Compared to the 72-hour extract, the 96-hour extract reveals slightly more intense peaks, suggesting an increased yield of bioactive compounds. This enhancement is particularly seen in the C–O and aromatic C=C regions, which are often associated with glycosides and flavonoids (Deokar & Pawar, 2021). These findings indicate that longer extraction times may improve the availability and recovery of phytochemicals, consistent with earlier reports on time-dependent extraction efficiency. The spectrum supports the phytochemical screening results in Table 2, reinforcing the presence of major bioactive classes in *Melastoma malabathricum* L. leaf extracts.

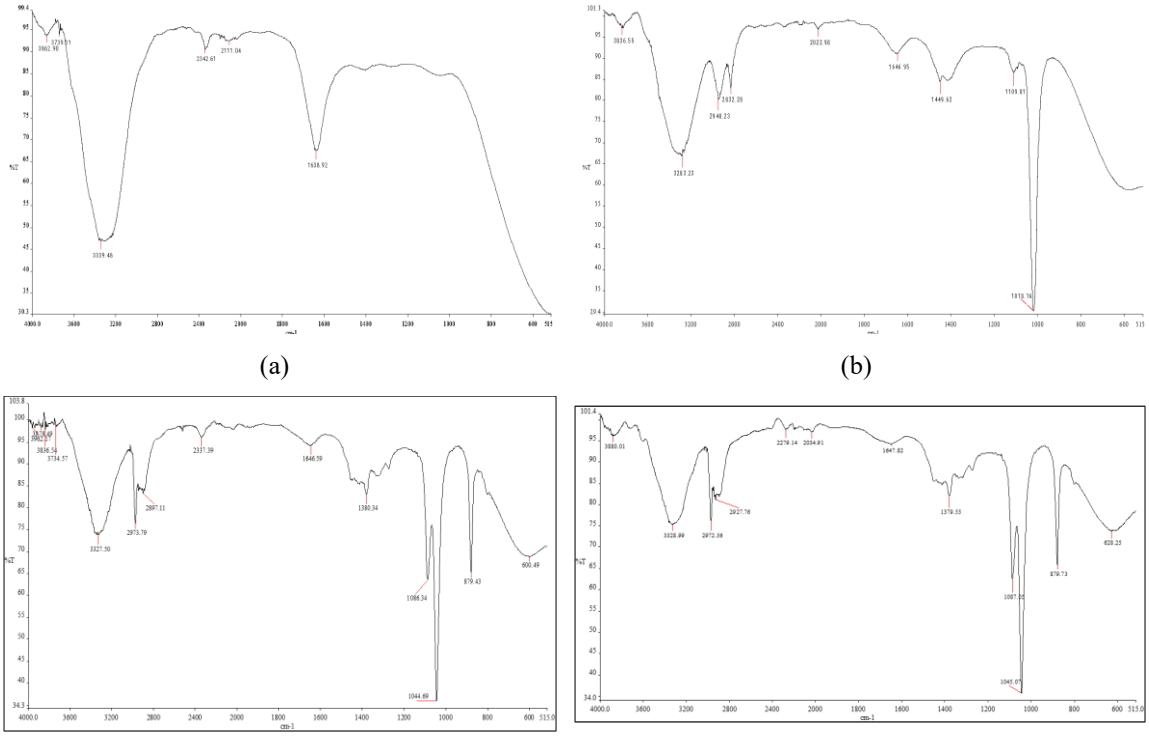

Fig. 3. FTIR spectrum – (a) 50% Methanol extract, (b) Methanol extract (96 hours), (c) 100% Ethanol extract, and (d) Ethanol extract (96 hours)

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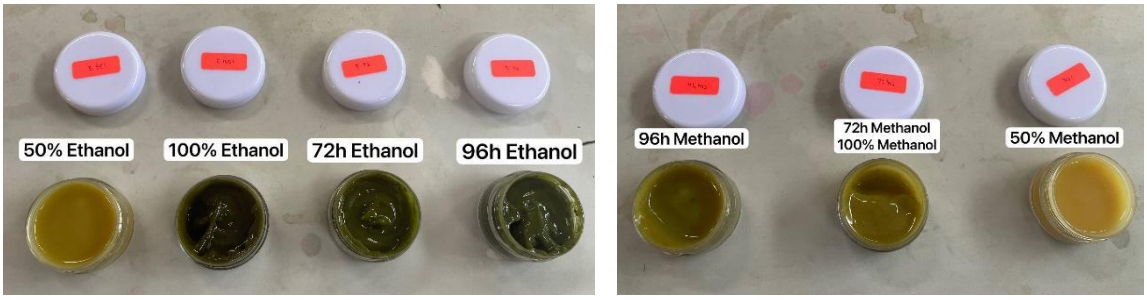
Formulation Water-Based Emulsion

The water-based emulsion (WBE) was successfully formulated with 1% (w/w) *Melastoma malabathricum* L. (Senduduk) leaf extracts, derived under various solvent extraction conditions. From Table 1, extracts obtained using 50% ethanol and methanol yielded higher masses, indicating better extraction efficiency due to balanced polarity, which allowed both hydrophilic and moderately lipophilic phytochemicals to be solubilized. These extracts were also more compatible with the emulsion matrix, producing visually smooth and stable emulsions, as shown in Fig. 4. Emulsions with these extracts exhibited homogeneous texture and color distribution, which suggests better dispersion of bioactive compounds.

In contrast, extracts from 100% solvents showed lower yield and caused slight formulation inconsistencies, such as faster separation and uneven coloration, though no major phase separation was observed during storage. Interestingly, darker coloration in some emulsions may reflect the presence of tannins and phenolics, which are natural plant pigments typically found in higher concentrations in methanolic or ethanolic extracts (Plaskova & Mlcek, 2023). Overall, all emulsions maintained physical stability throughout the observation period, demonstrating good compatibility of Senduduk extracts within the water-based emulsion system.



(a) (b)

Fig. 4. Formulation water-based emulsion; (a) Ethanol extract, (b) Methanol extract

Stability pH test

The pH stability of the formulated water-based emulsions (WBE), with and without MB leaf extract, was assessed over a 21-day storage period at 4°C to simulate refrigerated conditions. As shown in Table 3, the blank WBE maintained a relatively stable pH, ranging from 5.03 to 5.73 across all solvents and time intervals, indicating chemical stability under cold storage. This is expected due to the reduced enzymatic and microbial activity at lower temperatures, which helps maintain the integrity of the emulsion.

In contrast, the WBE with incorporated plant extract (WBE+PE) displayed slightly lower initial pH values (4.48–5.11), reflecting the presence of acidic phytochemicals such as phenolics, flavonoids, tannins, and organic acids commonly found in MB extracts (Plaskova & Mlcek, 2023). These acidic compounds contribute protons to the aqueous medium, lowering the pH. Over time, the pH of the WBE+PE samples showed mild increases, particularly in ethanol-based extracts, with the 96-hour ethanol extract reaching a peak of 5.61 on day 7 before stabilizing around 5.1 by day 21.

Notably, solvent concentration played a significant role; emulsions prepared with 50% methanol or ethanol had the lowest pH, while 100% solvents yielded higher, more stable pH values (around 4.71–5.04). This can be attributed to the broader polarity range of hydroalcoholic mixtures, which extract more acidic, water-soluble compounds. Despite these variations, all formulations remained within the ideal pH range of 4.5–5.5 for topical application, supporting both skin compatibility and potential preservative effects due to mild acidity (Lin et al., 2021).

https://doi.org/10.24191/scl.v20i2.10375

Therefore, the comparative analysis unequivocally establishes that 4°C storage provides significantly superior pH stability for both blank WBE and WBE+PE formulations. The lower temperature effectively minimizes pH fluctuations, slows down degradation processes, and helps maintain the pH within the desired range for topical application.

Table 3. Stability pH test with different extracts of *Melastoma malabathricum L.* leaves

Sample Description	pH							
	WBE				WBE+PE			
	0 day	7 days	14 days	21 days	0 day	7 days	14 days	21 days
72h Methanol	5.04	5.73	5.03	5.34	4.71	5.36	4.72	4.91
96h Methanol	5.04	5.73	5.03	5.34	4.64	5.33	4.65	4.86
72h Ethanol	5.04	5.73	5.03	5.34	4.88	5.57	5.10	5.11
96h Ethanol	5.04	5.73	5.03	5.34	4.91	5.61	5.11	5.10
50% Methanol	5.04	5.73	5.03	5.34	4.48	5.10	4.49	4.71
100% Methanol	5.04	5.73	5.03	5.34	4.71	5.36	4.72	4.91
50% Ethanol	5.04	5.73	5.03	5.34	4.56	5.15	4.62	4.62
100% Ethanol	5.04	5.73	5.03	5.34	4.86	5.49	5.00	5.04

Antibacterial activity test

From Table 4, the antibacterial testing showed that the pure plant extracts (PE) exhibited a moderate to strong zone of inhibition against both *Staphylococcus aureus* and *Escherichia Coli*. When conducting an antibacterial activity test, the parameters that are set to be constant are 100% solvent concentration and a 72-hour maceration period. Bacterial inhibition of *S. aureus* and *E. coli* after 96 hours of methanol extract treatment is illustrated in Fig. 5. For *S. aureus*, the highest inhibition was with 96h methanol extract (14 mm), followed by 50% methanol (9 mm) and 50% ethanol (8 mm). Similarly, *E. coli* was more sensitive overall, with the 96h methanol extract showing the largest inhibition zone of 19 mm, followed by 96h ethanol (12 mm), and 100% ethanol (11 mm). An inhibition zone of 6 mm was considered inactive, as it corresponds to the diameter of the filter paper disc and indicates no observable antibacterial effect. This supports the earlier phytochemical findings that the extract contains tannins, flavonoids, and saponins, which are known for their antimicrobial properties.

Table 4. Zone of inhibition (mm) for different extracts of *Melastoma malabathricum L.* leaves

Bacterial Strains	Sample Description	PE (mm)	WBE (mm)	WBE + PE (mm)
Staphylococcus Aureus	72h Methanol	9	0	6
	96h Methanol	14	0	9
	50% Methanol	8	0	6
	100% Methanol	9	0	6
	72h Ethanol	8	0	8
	96h Ethanol	9	0	8
	50% Ethanol	8	0	7
	100% Ethanol	9	0	8
Escherichia Coli	72h Methanol	19	0	14
	96h Methanol	19	0	17
	50% Methanol	10	0	8
	100% Methanol	19	0	14
	72h Ethanol	10	0	9
	96h Ethanol	12	0	10
	50% Ethanol	9	0	8
	100% Ethanol	11	0	10

https://doi.org/10.24191/scl.v20i2.10375

(a) (b)

Fig. 5. Bacterial Inhibition on (a) *Staphylococcus aureus* and (b) *Escherichia coli* with 96h methanol extract

None of the WBE (water-based emulsion without plant extract) samples exhibited any antibacterial activity, as all inhibition zones measured 0 mm for both bacterial strains. This is anticipated, given that the base emulsion lacks any active antimicrobial agents. Nevertheless, the findings for WBE + PE (emulsion containing 1% plant extract) are notable. Although the inhibition zones were generally smaller compared to those observed with pure plant extract, there was still detectable antibacterial activity. For example, the 96-hour methanol WBE + PE demonstrated inhibition zones of 9 mm against *S. aureus* and 17 mm against *E. coli*, which remain significant. (Halim et al., 2025)

The slightly reduced effectiveness of WBE + PE compared to pure PE could be due to the dilution effect; the plant extract in the emulsion was present at only 1%, which may have limited the concentration of active compounds in contact with the bacteria. Additionally, the presence of oil or stabilizers in the emulsion could have affected the diffusion of the active compounds through the agar, leading to smaller inhibition zones. This is a common issue in emulsion-based delivery techniques when bioavailability is compromised due to encapsulation or interaction with emulsifiers.

Therefore, the results confirm that *Melastoma malabathricum* L. extracts have measurable antibacterial activity, particularly when prepared using methanol and longer extraction times. The combination of the extract with a water-based emulsion still retains some antibacterial potential, though the reduced concentration of actives may limit its full effectiveness. These findings suggest potential for further development into antimicrobial formulations but also highlight the need for optimization of emulsion concentration, solvent selection, and possibly using higher extract loads in WBE to enhance performance.

CONCLUSION

In conclusion, MB leaf extracts demonstrated notable antibacterial activity, particularly when extracted using methanol over a period of 96 hours. The extract showed greater inhibition against *Escherichia coli* compared to *Staphylococcus aureus*, indicating its potential effectiveness against both Gram-negative and Gram-positive bacteria. Phytochemical screening confirmed the presence of bioactive compounds, including tannins, saponins, and flavonoids, which likely contributed to this antimicrobial effect. Although the water-based emulsion containing 1% extract also exhibited antibacterial activity, its efficacy was lower than the pure extract due to dilution and reduced compound diffusion. Overall, the findings support the potential use of MB extract as a natural antibacterial agent, with further optimization needed for formulation and concentration to enhance its practical application.

https://doi.org/10.24191/scl.v20i2.10375

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the financial support received from MYRA-PHD (600-RMC/GPM LPHD 5/3 (065/2023)), Research Management Centre (RMC) and Faculty of Chemical Engineering, Universiti Teknologi MARA, Shah Alam, Selangor, Malaysia.

CONFLICT OF INTEREST STATEMENT

The authors agree that this research was conducted in the absence of any self-benefits, commercial or financial conflicts and declare the absence of conflicting interests with the funders.

AUTHORS' CONTRIBUTIONS

Siti Nur 'Aisyah Norrizam carried out research, analyzed data, and wrote the draft article. Norashikin Ahmad Zamanhuri conceptualized the research idea, supervised the research progress, provided feedback on the draft article, and revised the final version of the article. Norasmah Mohammed Manshor assisted with data interpretation, reviewed, and proofread the article.

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